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10/539980
JC09 Rec'd PCT/PTO 19 JUN 2005

SENSING LIGHT EMITTED FROM MULTIPLE LIGHT SOURCES

The technical field of this disclosure is light production from light emitting diodes (LEDs), particularly, sensing light emitted simultaneously from multiple light sources.

Illumination sources, such as lamps, currently utilize incandescent and fluorescent means as light production. It is well known that incandescent light sources are inefficient light sources that utilize more power resources than other light sources. Fluorescent light sources have provided a more efficient light production.

Light emitting diodes (LEDs) produce light in a much more efficient manner than incandescent light sources, but until recently have not been manufactured in a cost efficient manner to utilize in lighting applications. Expectations are for LEDs to produce light more efficiently than fluorescent light sources in the near future. Recently, LED production has made utilizing LEDs in light production applications a viable alternative.

Producing usable light with LEDs generally requires either manufacturing an LED that produces a specified color, such as utilizing a phosphor layer overlying the LED, or mixing a plurality of colored LEDs to produce a desired colored light output. Unfortunately, once a light source package is produced to achieve the desired colored light output its useful life is reduced to the amount of time until a failure or partial failure of one of its component parts occurs.

Unfortunately, LED characteristics depend on temperature, drive current, and time. Additionally, LED characteristics vary from LED to LED. Although an LED-based lamp may be set to operate at a given color point and intensity, at the beginning of its life, the actual color and intensity obtained at that setting may not remain constant.

Mixing a plurality of colored light sources may include a control system that varies individual light source contributions to correct for variation in the LED characteristics That is, as the output of component LEDs varies, the control system can maintain a desired spectral output and intensity by varying individual LED output to compensate for the variations.

Currently, sensing systems for controlling a specified colored light output include temperature feed-forward or intensity feedback systems containing a single unfiltered photodiode. Another sensing system includes utilizing multiple photodiodes, for example three or more, and corresponding color filters. This system may be referred to as a color filter photodiode control system.

In one embodiment, this system can be implemented utilizing a time-based approach whereby the LEDs are pulsed on and off in a particular pattern allowing the sensing of the intensity of the independent LED groups. An advantage of the color filter photodiode control system over the temperature feed-forward or intensity feedback systems is that the color filter photodiode control system can sense the average levels of the different spectral outputs of the LEDs, for example red, green, and blue, without having to turn the LEDs on and off in a particular pattern. Additionally, a low pass filter can be used to integrate the signal from each LED group. The accuracy of this method is strongly influenced by the color filters on the photodiodes.

Unfortunately, as described above, temperature feed-forward or intensity feedback systems require that LEDs be turned on and off briefly to permit sensing of the individual color components, for example red, green and blue. This approach is susceptible to errors resulting from ripple in the driving current, and changes in the drive waveform, such as, for example changes in the rise and fall times of the LED drive current pulses. The color filter photodiode control system, although not requiring the turning on and off of LEDs to sense the individual color components, does require more expensive sensors containing color filters as well as a larger total number of sensors. None of the systems corrects for ambient light.

It would be desirable, therefore, to provide a system that would overcome these and other disadvantages.

The present invention is directed to an apparatus and method for controlling a light source. The invention provides for a frequency sensing structure that produces an intensity value input for a control system.

One aspect of the invention provides a light source control apparatus including at least one light source that emits a light signal at a discrete frequency and a reference signal at the discrete frequency. The apparatus further includes a photodetector optically coupled to the light source and designed to receive the light signal. The apparatus additionally includes at least one lock-in system coupled to the photodetector and each light source, to receive the light signal from the photodetector and an associated reference signal from the light source. Each lock-in system produces an intensity value of the light source based on the light signal and the associated reference signal.

In accordance with another aspect of the invention, the invention provides a method for sensing intensity of a light source. The method includes emitting at least one light signal where the light source is driven at a discrete frequency. The method further includes transmitting a reference signal associated with each of the light signals at the discrete frequency. The method additionally includes producing an intensity value based on the light signal and the associated reference signal.

In accordance with yet another aspect of the invention, the invention provides a system for sensing intensity of a light source. The system includes means for emitting at least one light signal where the light source is driven at a discrete frequency. The system further includes means for transmitting a reference signal associated with each of the light signals at the discrete frequency. Means for producing an intensity value based on the light signal and the associated reference signal are also included.

The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

FIG. 1 is a schematic diagram illustrating a sensing device according to an embodiment of the present invention;

FIG. 2 is a schematic diagram illustrating a portion of the sensing device in **FIG. 1** according to an embodiment of the present invention;

FIG. 3 is a schematic diagram illustrating another portion of the sensing device in **FIG. 1** according to an embodiment of the present invention;

FIG. 4 is a schematic diagram illustrating a sensing device according to another embodiment of the present invention; and

FIG. 5 is a flow diagram depicting an exemplary method in accordance with the present invention.

Throughout the specification, and in the claims, the term "connected" means a direct physical or optical connection between the things that are connected, without any intermediate devices. The term "coupled" means either a direct physical or optical connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term "circuit" means either a single component or a multiplicity of components, either active or passive, that are coupled together to perform a desired function.

FIG. 1 is a schematic diagram illustrating a sensing device **100** according to an embodiment of the present invention. Device structure **100** includes control units **(110, 120,** and **130)**, light emitting diodes **(115, 125** and **135)**, a photodetector **150**, and lock-in systems **(170, 180**, and **190)**. In one embodiment, implementation of the present invention allows any number of light emitting diodes (LEDs) to be utilized, so long as there is a corresponding control unit and lock-in system for each LED. In another embodiment, each LED represents a block of independently-driven LEDs with a substantially similar spectral light output. For example, LED **115** may consist of several LEDs, all emitting a red light output. Similarly, LED **125** may include all green light emitting LEDs, and LED 135 may include all blue light emitting LEDs.

In one example, the present invention is implemented as a single LED or a single color group of LEDs, a single control unit, and a single lock-in unit in addition to the photodetector. In another example and referring to **FIG. 1**, sensing device **100** is implemented as a plurality of LEDs or multi-color LED groups, each independently-driven LED or LED group having an associated control unit and an associated lock-in system. In this example, emitted spectra of the LEDs form a multi-source light signal. For example, a red, a green, and a blue LED or groups of LEDs are utilized to produce a "white" multi-source light signal.

Each control unit (**110, 120**, and **130**), detailed in **FIG. 2** below, includes an associated output drive signal terminal (Drv1, Drv2, and Drv3) and an associated output reference terminal (Ref1, Ref2, and Ref3). Each output drive signal terminal (Drv1, Drv2, and Drv3) is coupled to an associated light emitting diode (**115, 125** and **135**).

In an example, output drive signal terminal (Drv1) is coupled to light emitting diodes (**115**), output drive signal terminal (Drv2) is coupled to light emitting diode (**125**), and output drive signal terminal (Drv3) is coupled to light emitting diode (**135**).

Light emitting devices (**115, 125** and **135**) are optoelectronic devices that produce light when power is supplied causing them to forward bias. The light produced may be within the blue, green, red, amber or other portion of the spectrum, depending on the material utilized in manufacturing the LED. In an example, LEDs (**115, 125** and **135**) are implemented as LXHL-BM01, LXHL-BB01 and LXHL-BD01 available from Lumileds corporation of San Jose, CA. In another example, LEDs (**115, 125** and **135**) are implemented as NSPB300A, NSPG300A and NSPR800AS from Nichia corporation of Mountville, PA.

Each control unit produces a drive signal and a reference signal, as detailed in **FIG. 2** below. Power, in the form of the drive signal, is transmitted to the associated light emitting diode (LED) or LED group and the reference signal is transmitted to the associated lock-in unit. The LED receives the drive signal and produces a light signal based on the drive signal. The drive signal is generated at a discrete frequency.

The reference signal is transmitted to the associated lock-in system and includes the same discrete frequency. Multiple control units and associated LEDs produce a light signal including several intensity values representing the intensity of light emitted by each LED or LED group.

It is important to differentiate between the discrete frequency driving the light signal emitting from each LED or LED group and the very high frequency that the LED or LED group emit as light. Typically, as described below, the drive signals range from about 400 Hz to about 1.2 kHz while the light emitted from the LEDs or LED groups is in the order of 10^{14} Hz.

Photodetector **150** is an optoelectronic device that responds to light signals and produces a received light signal. In one embodiment, photodetector **150** is implemented as a photodiode, such as, for example PS 1-2CH from Pacific Silicon Sensor, Inc of Westlake Village, CA. Photodetector **150** includes an output signal terminal (Rec) for supplying the received light signal.

In one embodiment, photodetector **150** responds to a single source light signal and produces a received light signal, at the output signal terminal (Rec), which corresponds to the intensity of light produced by that single light source. In another embodiment and described in **FIG. 5** below, photodetector **150** responds to the multi-source light signal and produces a received light signal, at the output signal terminal (Rec). The received light signal includes components at multiple frequencies, each component corresponding to the intensity of one light source in the multi-source light signal.

Each lock-in system (**170**, **180**, and **190**) includes a lock-in device, detailed in **FIG. 3** below. Each lock-in system (**170**, **180**, and **190**) further includes an input signal terminal (Rec) and an associated input reference terminal (Ref1, Ref2, and Ref3). Each input signal terminal (Rec) of each associated lock-in system (**170**, **180**, and **190**) is coupled to the output signal terminal (Rec) of photodetector **150**. Each input reference terminal (Ref1, Ref2, and Ref3) of each associated lock-in system (**170**, **180**, and **190**) is coupled to the output reference terminal (Ref1, Ref2, and Ref3) of each associated control unit (**110**, **120**, and **130**).

In an example, output reference terminal (Ref1) of control unit **110** is coupled to input reference terminal (Ref1) of lock-in system **170**, output reference terminal (Ref2) of control unit **120** is coupled to input reference terminal (Ref1) of lock-in system **180**, and output reference terminal (Ref3) of control unit **130** is coupled to input reference terminal (Ref3) of lock-in system **190**.

Each lock-in system (**170**, **180**, and **190**) further includes an associated output intensity signal terminal (Int1, Int2, and Int3), detailed in **FIG. 3** below. Each lock-in system receives an input signal, at the input signal terminal (Rec), from photodetector **150** and a reference signal, at the input reference terminal (Ref1, Ref2, and Ref3), from an associated control unit (**110**, **120**, and **130**). Each lock-in system produces an output intensity signal, at the associated output intensity signal terminal (Int1, Int2, and Int3), based on the received input signal and reference signal.

In a further embodiment, sensing device **100** includes a high-pass filter coupled between the output reference terminal (Ref1, Ref2, and Ref3) of each control unit (**110**, **120**, and **130**) and the input reference terminal (Ref1, Ref2, and Ref3) of the associated lock-in system (**170**, **180**, and **190**). In one embodiment, coupling a high-pass filter between the control unit and the lock-in system reduces spurious dc components from affecting the reference signal.

FIG. 2 is a schematic diagram illustrating a control unit **210** according to an embodiment of the present invention. Control unit **210** includes a frequency shifter **215**, a power distributor **217**, an input clock signal terminal (Clk), an input power signal terminal (Pwr), an output reference signal terminal (Ref), and an output drive signal terminal. Control unit **210** receives a clock signal and a power signal, produces a reference signal based on the clock signal, and produces a drive signal based on the reference signal and the power signal.

Frequency shifter **215** includes an input clock signal terminal (Clk) and an output reference signal terminal (Ref). Frequency shifter **215** receives the clock signal and produces the reference signal based on the clock signal. In one embodiment, frequency shifter **215** receives the clock signal and "divides down" the clock signal to produce the reference signal. The reference signal frequency utilized is produced at a frequency so as not to cause noticeable "flicker" to the human eye. In an example, a reference signal is produced in the 100 Hz – 2.4 kHz range.

In another embodiment, frequency shifter **215** includes an internal clock that generates the clock signal internally thereby eliminating the need for the clock terminal (Clk).

Additionally and referring to **FIG. 1**, the use of multiple control units (**110**, **120**, and **130**) requires several discrete frequencies. The frequencies utilized are produced so that frequency overlap will not occur. In one embodiment, the frequencies utilized are produced with a 100 Hz gap between discrete frequencies. In an example, control unit **110** produces a reference frequency at 400 Hz, control unit **120** produces a reference frequency at 500 Hz, and control unit **130** produces a reference frequency at 600 Hz.

Power distributor **217** includes an input power terminal (Pwr), an input reference signal terminal (Ref), and an output drive signal terminal (Drv). The input reference terminal (Ref) of power distributor **217** is coupled to the output reference terminal (Ref) of frequency shifter **215**. Power distributor **217** receives the power signal and the reference signal and produces the drive signal based on the power signal and the reference signal.

In one embodiment, the power signal is implemented as a voltage source signal. In another embodiment, the power signal is implemented as a current source signal. In an example, power distributor **217** produces a drive signal including a current signal modulated at a discrete frequency associated with the reference signal.

The power signal may be produced in the form of one of several different waveforms, such as, for example, a sine wave, a cosine wave, a square wave, or any other waveform that would allow the production of the light signal.

FIG. 3 is a schematic diagram illustrating a lock-in device **370** according to an embodiment of the present invention. Lock-in device **370** includes a signal multiplier **375**, a filter **377**, an input signal terminal (Rec), an input reference terminal (Ref), and an output intensity terminal (Int). Lock-in device **370** receives an input signal and a reference signal, and produces an intensity signal based on the input signal and the reference signal.

Signal multiplier **375** includes an input signal terminal (Rec), an input reference terminal (Ref), and an output product terminal (Prd). Signal multiplier **375** receives the input signal and the reference signal, and produces a product signal based on the input signal and the reference signal. Signal multiplier **375** produces the product signal by multiplying the input signal by the reference signal, detailed in **FIG. 5** below. Signal multiplier **375** can be implemented as a signal multiplier chip, such as, for example the MLT04 produced by Analog Devices of Norwood, MA.

Filter **377** includes an input product terminal (Prd) and an output intensity terminal (Int). The input product terminal (Prd) of filter **377** is coupled to the output product terminal (Prd) of signal multiplier **375**. Filter **377** receives the product signal and filters the received product signal to remove non-dc portions of the signal. In one embodiment, filter **377** is implemented as a low-pass filter.

FIG. 4 is a schematic diagram illustrating a sensing device **400** according to another embodiment of the present invention. Device structure **400** includes control units (**110, 120,** and **130**), light emitting diodes (**115, 125** and **135**), photodetectors **450** and **455**, and lock-in systems (**470, 480,** and **490**). Like components from **FIG.1** are numbered identically and function identically. In one embodiment, implementation of the present invention allows any number of light emitting diodes (LEDs) to be utilized, so long as there is a corresponding control unit and lock-in system for each independently driven LED or group of LEDs.

Photodetectors **450** and **455** are optoelectronic devices that respond to light signals across the whole visible spectrum, and each produce a received light signal within a predetermined spectrum. In one embodiment, photodetectors **450** and **455** are implemented as two separate single junction photodiodes, such as, for example PSS 1-2CH from Pacific Silicon Sensor, Inc. In this embodiment, photodetector **450** includes an output signal terminal (Rec1) for supplying a portion of the received light signal, and photodetector **455** includes an output signal terminal (Rec2) for supplying another portion of the received light signal.

In another embodiment, photodetectors **450** and **455** are implemented as a multi-junction photodiode, such as, for example PSS-WS7.56 from Pacific Silicon Sensor, Inc. In this embodiment, photodetector **450** represents a first junction of the multi-junction photodiode, and photodetector **455** represents a second junction of the multi-junction photodiode. One junction is more sensitive to red wavelengths, and the other is more sensitive to blue wavelengths. Comparison of the measurements of the two junctions provides a measure of spectral shift.

In an example, photodetector **450** responds more strongly than photodetector 455 to light signals within the spectrum defined as greater than about 600nm. In this example, photodetector **455** responds most strongly than photodetector 450 to light signals within the spectrum defined as less than about 600nm.

Photodetectors **450** and **455** respond to single and multi-source light signals and produce a received light signal, at the output signal terminals (Rec1 and Rec2). In one embodiment, each received light signal includes single or multiple intensity values. In this embodiment, each intensity value includes a discrete frequency.

In another embodiment, each received light signal includes components at single or multiple frequencies. In this embodiment, each component corresponds to the intensity of one light source in the multi-source light signal.

Each lock-in system (**470, 480**, and **490**) includes multiple lock-in devices (**475, 477, 485, 487, 495**, and **497**), each lock-in device functions as described in **FIG. 3** above. In one embodiment, the number of lock-in devices within each lock-in system is equal to the number of photodetectors. In an example, lock-in devices (**475, 485**, and **495**) are coupled to photodetector **450** via input signal terminal (Rec1), and lock-in devices (**477, 487**, and **497**) are coupled to photodetector **455** via input signal terminal (Rec2).

Each lock-in system (**470, 480**, and **490**) further includes associated input reference terminals (Ref1, Ref2, and Ref3). Input reference terminals (Ref1, Ref2, and Ref3) of each associated lock-in system (**470, 480**, and **490**) are coupled to the output reference terminal (Ref1, Ref2, and Ref3) of each associated control unit (**110, 120**, and **130**). In an example, output reference terminal (Ref1) of control unit **110** is coupled to each input reference terminal (Ref1) of lock-in devices (**475** and **477**) within lock-in system **470**. Output reference terminal (Ref2) of control unit **120** is coupled to input reference terminal (Ref1) of lock-in devices (**485** and **487**) within lock-in system **480**. Output reference terminal (Ref3) of control unit **130** is coupled to input reference terminal (Ref3) of lock-in devices (**495** and **497**) within lock-in system **490**.

Each lock-in device (**475, 477, 485, 487, 495**, and **497**) further includes multiple output intensity signal terminals (Int1/1, Int2/1, Int1/2, Int2/2, Int1/3, and Int2/3). In one embodiment, the number of output intensity signal terminals within each lock-in system is equal to the number of lock-in devices, and therefore is equal to the number of photodetectors.

Each lock-in device receives a portion of the received light signal from an associated photodetector, and receives a reference signal from an associated control unit. Each lock-in system produces an output intensity signal, at the associated output intensity signal terminal (Int1/1, Int2/1, Int1/2, Int2/2, Int1/3, and Int2/3), based on the received input signal and reference signal.

In a further embodiment, sensing device **100** includes a high-pass filter coupled between the output reference terminal (Ref1, Ref2, and Ref3) of each control unit (**110**, **120**, and **130**) and the input reference terminal (Ref1, Ref2, and Ref3) of the associated lock-in system (**470**, **480**, and **490**). In one embodiment, coupling a high-pass filter between the control unit and the lock-in system reduces spurious dc components from affecting the reference signal.

FIG. 5 is a flow diagram depicting an exemplary method for sensing intensity of a light source in accordance with the present invention. Method **500** may utilize one or more systems detailed in **FIGS. 1–4**, above.

Method **500** begins at block **510** where a control system for a light source determines a need to sense the intensity of one or more light emitting diodes (LEDs) or groups of LEDs within the light source. Method **500** allows the control system to determine power requirements for each LED by providing the control system with an intensity value for each LED or group of independently-driven LEDs. Method **500** then advances to block **510**.

At block **510**, the light source emits a light signal. Referring to **FIGS. 1** and **2**, the light source includes at least one light emitting diode (LED) or group of LEDs, each independently-driven LED or group of LEDs emitting a light signal that includes an intensity value within the LED's spectral band, and being driven with a current waveform at a discrete frequency.

In an example, the light source includes three LEDs or groups of LEDs, each LED or group of LEDs coupled to and receiving a drive signal from an associated control unit (**110**, **120**, and **130**), and combining to produce a "white" light output. That is, LED (**115**) is driven with an AC current at a frequency ω_R and emits light in the red spectrum, LED (**125**) is driven with an AC current at a frequency ω_G and emits light in the green spectrum, and LED (**135**) is driven with an AC current at a frequency ω_B and emits light in the blue spectrum. For

illustrative purposes, a cosine waveform is utilized. The resulting light signal is then expressed as:

$$A_R \cos\omega_R t + A_G \cos\omega_G t + A_B \cos\omega_B t$$

where A is the magnitude and ω is the frequency of the associated signal.

In this example control unit (**110**) and LED (**115**) produce the $A_R \cos\omega_R t$ component, control unit (**120**) and LED (**125**) produce the $A_G \cos\omega_G t$ component, and control unit (**130**) and LED (**135**) produce the $A_B \cos\omega_B t$ component. In this example and referring to **FIG. 1**, the red LED (**115**) is driven at 400 Hz (ω_R), the green LED (**125**) is driven at 500 Hz (ω_G), and the blue LED (**135**) is driven at 600 Hz (ω_B).

In one embodiment, a square wave is utilized as the waveform characteristics include the ability to set the lower portion of the waveform to zero amps. The ability to set the lower portion of the waveform to zero is important as it allows for cancellation of undesirable components during production of an output intensity signal.

In one embodiment and referring to **FIGS. 1** and **3** above, the light signal is received by photodetector **150** and transmitted to each lock-in system (**170, 180,** and **190**) as the received light signal. In another embodiment and referring to **FIGS. 3** and **4** above, the light signal is received by photodetectors **450** and **455**, and transmitted to each lock-in system (**470, 480,** and **490**) as the received light signal.

In this embodiment, a portion of the received light signal, received by photodetector **450**, is transmitted to one lock-in device (**475, 485,** and **495**) within each lock-in system (**470, 480,** and **490**). Additionally, another portion of the signal, received by photodetector **455**, is transmitted to the other lock-in device (**477, 487,** and **497**) within each lock-in system (**470, 480,** and **490**). Method **500** then advances to block **520**.

At block **520**, the control unit transmits a reference signal to an associated lock-in system. In one embodiment and referring to **FIG. 1**, each control unit (**110, 120,** and **130**) transmits an associated reference signal to an associated lock-in system (**170, 180,** and **190**). In this embodiment, each reference signal is produced by the associated control unit and transmitted at a discrete frequency.

In an example and referring to **FIGS. 1** and **2**, control unit **210** receives the clock signal and produces the reference signal based on the clock signal. Alternatively and detailed in **FIG. 2** above, the frequency could be generated internally within each controller thereby negating the need for an external clock. Additionally, for illustrative purposes a cosine waveform is utilized. The resulting reference signal is then expressed as:

$$I_{ref} \cos\omega_{ref}t$$

where I_{ref} is the magnitude and ω_{ref} is the frequency of the reference signal.

In this example, the reference signal produced by control unit **120** is expressed as:

$$I_{ref} \cos\omega_{G}t$$

The reference signal is then transmitted to each lock-in system. In one embodiment, the reference signal is transmitted to each lock-in system (**170**, **180**, and **190**) as the reference signal of **FIG.1**, above. In another embodiment, the reference signal is transmitted to each lock-in system (**470**, **480**, and **490**) as the reference signal of **FIG. 4**, above. Method **500** then advances to block **530**.

At block **530**, the lock-in system produces an intensity value based on the received light signal and the associated reference signal. In one embodiment and referring to **FIG. 1**, each lock-in system (**170**, **180**, and **190**) receives the received light signal from photodetector **150** and receives an associated reference signal from an associated control unit (**110**, **120**, and **130**).

In an example and referring to **FIGS. 1** and **3**, signal multiplier **375** of lock-in device **370** receives the received light signal and the associated reference signal. In this example, signal multiplier **375** produces a product signal by multiplying the received light signal by the associated reference signal. The resulting product signal is then expressed as:

$$I_{ref}*A_R \cos\omega_{ref}t \cos\omega_R t + I_{ref}*A_G \cos\omega_G t * \cos\omega_R t + I_{ref}*A_B \cos\omega_B t * \cos\omega_R t$$

multiplication of the cosine terms results in the product signal expressed as :

$$\tfrac{1}{2}I_{ref}{*}A_R\cos(\omega_{ref}-\omega_R)t+\tfrac{1}{2}I_{ref}{*}A_R\cos(\omega_{ref}+\omega_R)t+\tfrac{1}{2}I_{ref}{*}A_G\cos(\omega_{ref}-\omega_G)t+\tfrac{1}{2}I_{ref}{*}A_G\cos(\omega_{ref}+\omega_G)t+\tfrac{1}{2}I_{ref}{*}A_B\cos(\omega_{ref}-\omega_B)t+\tfrac{1}{2}I_{ref}{*}A_B\cos(\omega_{ref}+\omega_B)t$$

In this example and described above, lock-in device **370** represents the lock-in device within lock-in system **180** of **FIG. 1**, above. Therefore, the resulting reference signal is produced by control unit **120** and expressed as:

$$I_{ref}\cos\omega_{ref}t = I_{ref}\cos\omega_G t$$

substitution results in the product signal expressed as:

$$\tfrac{1}{2}I_{ref}{*}A_R\cos(\omega_G-\omega_R)t+\tfrac{1}{2}I_{ref}{*}A_R\cos(\omega_G+\omega_R)t+\tfrac{1}{2}I_{ref}{*}A_G+\tfrac{1}{2}I_{ref}{*}A_G\cos2\omega_G t+\tfrac{1}{2}I_{ref}{*}A_B\cos(\omega_G-\omega_B)t+\tfrac{1}{2}I_{ref}{*}A_B\cos(\omega_G+\omega_B)t$$

In this example, the product signal is then transmitted to filter **377**. Filter **377** is implemented as a low-pass filter having a cutoff frequency that discards the non-dc terms. The cutoff frequency must be less than either ($\omega_G - \omega_R$) or ($\omega_G - \omega_B$), for example, below 100 Hz when utilizing the above example frequencies. The result of filtering the product signal is removal of the non-dc terms and is expressed as:

$$\tfrac{1}{2}I_{ref}{*}A_G$$

In this example and referring to **FIGS. 1** and **3**, the resulting signal is the intensity value. The reference intensity value may be removed, for example, by "dividing" it out. Alternatively, an unaltered intensity value can be returned to the control system.

In another embodiment and referring to **FIG. 4**, each lock-in system (**470**, **480**, and **490**) receives the received light signal from photodetectors **450** and **455**, and receives an associated reference signal from an associated control unit (**110**, **120**, and **130**). In this embodiment, one lock-in device of each lock-in system, for example lock-in device **485** of lock-in system **480**, receives a portion of the received light signal. The second lock-in device of each lock-in system, for example lock-in device **487** of lock-in system **480**, receives another portion of the received light signal. Each lock-in device (**485** and **487**) produces a component intensity value at the associated intensity signal terminal (Int1/2, Int2/2), as described above. In an example, the component intensity values are summed to produce a single intensity value for the associated spectrum (e.g. Green). In an example, the ratio of the two components values provides a measure of any spectral shifts that may have occurred during light source operation. Method **500** then advances to block **550**, where it returns the intensity values to the control system.

The control system utilizes the intensity values to determine the amount of power to supply to the LEDs of the light source. In one embodiment and referring to **FIG. 1**, the control system determines power adjustment requirements by cross indexing each provided LED intensity value with a thermal value (already received). In an example, each provided LED intensity value and thermal value are cross indexed in a look-up table that includes manufacturer provided data and/or data obtained from LED calibration in the factory. The resultant value obtained from the look-up table, for each LED, is then utilized by the control system to determine an actual contribution of each LED or independently-driven LED group to the light source. Power supplied to each LED is then adjusted accordingly.

In another embodiment and referring to **FIG. 4**, the control system determines power adjustment requirements by cross indexing each provided summed LED intensity value with a ratio of the component intensity values in a look-up table that includes manufacturer provided data and/or data obtained from LED calibration in the factory. The resultant value obtained from the look-up table, for each LED or independently-driven LED group, is then utilized by the control system to determine an actual contribution of each LED to the light source. Power supplied to each LED is then adjusted accordingly.

The above-described apparatus and method for sensing light emitted simultaneously from multiple light sources are example methods and implementations. These methods and implementations illustrate one possible approach for sensing light emitted simultaneously from multiple light sources. The actual implementation may vary from the method discussed. Moreover, various other improvements and modifications to this invention may occur to those skilled in the art, and those improvements and modifications will fall within the scope of this invention as set forth in the claims below.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive.